

# NEW RADIOFREQUENCY EXPOSURE SYSTEM WITH REAL TELECOMMUNICATION SIGNALS

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**Abstract.** In recent years, there has been an increase in the number of studies on biological effects of Electromagnetic (EM) fields emitted from Base Transceiver Stations (BTSs). The biological effects of generated and real telecommunication signals produced by different types of exposure systems are discussed. However, the proper exposure methods for such experiments are very limited. We successfully developed a simple and cost-effective exposure unit with real GSM/DCS/UMTS signal from BTS containing proper modulations or intermittence (continuous, interrupted). Signal processing and conditioning unit is based on a Radiofrequency (RF) repeater. The downlink signal is filtered by integrated high selectivity pass-band filters and amplified to a required level. The main part of exposure unit is a Faraday cage with the specimen (exposure) area measuring  $150 \times 250$  mm with E-field percent deviation less than 18 %. This exposure system can be helpful in experiments with living organisms in in vivo studies and in vitro studies with normal or pathological cells as well as other micro scale structures exposed to RF EM fields from BTS.

## Keywords

*Base transceiver station, electromagnetic field effects, exposure unit, mobile communication.*

## 1. Introduction

Radiofrequency (RF) sources of mobile communication use telecommunication channels, which are realized by either various carrier signal frequencies (FDMA - Frequency-Division Multiple Access), time slots allocated on a carrier signal (TDMA - Time-Division Multiple Access), or pseudo-random codes used to spread a signal frequency spectrum (CDMA - Code-Division Multiple Access). A service area is split into the cells in a cellular network, where each area is covered by a single base station signal. In a forward link (downlink), i.e. in direction from a Base Transceiver Station (BTS) to a cell phone, all cell subscribers receive signal from one BTS and interference signals from the other BTSs at the same time. In a reverse link (uplink), i.e. in a direction from a mobile unit to BTS, the mobile units themselves produce the interference signals [1].

The GSM (Global System for Mobile Communications) and DCS (Digital Cellular System) standards combine FDMA and TDMA, while one carrier frequency comprises eight time slots. The duplex transmission is secured by FDD/TDD combination (the frequency and time division duplex) that separates uplink and downlink directions. Thus, there is a time delay by three time slots between uplink and downlink, and

also frequency shift, where for uplink (GSM900: 890–915 MHz; DCS1800: 1710–1785 MHz) was selected lower region of frequency band comparing to downlink (GSM900: 935–960 MHz; DCS1800: 1805–1880 MHz) signal. The GSM and DCS signals are transmitted with GMSK modulation (Gaussian Minimum Shift Keying).

The UMTS (Universal Mobile Telecommunications System) is currently most used 3<sup>rd</sup> generation standard in the Europe. It is based on CDMA with FDD (wideband CDMA) and TDD (time division CDMA) conceptions. In FDD, uplink (1920–1980 MHz) and downlink (2110–2170 MHz) signals are separated by the frequency bands. There is also some difference in the frame structure. In an uplink signal, data and control channels are code-associated and in a downlink the data and control channels are time-associated. In TDD, uplink and downlink are transmitted using the same carrier frequency within two frequency bands, 1900–1920 MHz and 2010–2025 MHz. These bands are separated by 15 synchronized time slots, which are divided into transmitting and receiving slots. Downlink is transmitting with conventional QPSK modulation (Quadrature Phase-Shift Keying) and uplink with dual-channel QPSK modulation.

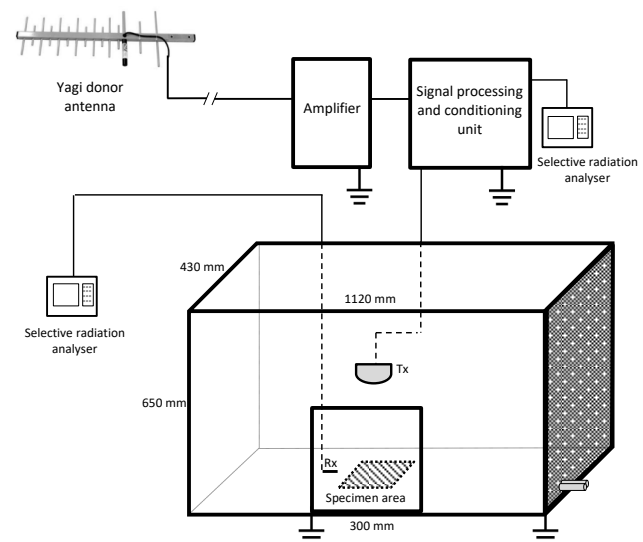
There is a strong evidence showing that different signals in mobile communication may produce different effects dependent on carrier frequency, modulation, polarization, and other physical parameters presented in [2], [3], [4] and [5]. This circumstance demands validation of biological activity for different signals using relevant exposure systems. Typically, there are three methods to produce GSM or UMTS signals. The first method is based on the use of an ordinary cell phone to generate RF signal. The exposure to EM fields from a cell phone provides real conditions of exposure for assessing possible detrimental effects of mobile communication. However, the use of ordinary cell phone for mechanistic studies is impractical due to a limitation by the cell itself and mobile provider which is currently in use. In addition, the ordinary cell phones are fully automated devices, so it is not possible to select neither frequency band nor radiated power. Thus, replication of such studies is limited. The second method is to use CW (Continuous Wave) signal, so called "mobile phone-like" signal, with a frequency corresponding to UMTS, GSM or similar carrier frequency. However, this signal does not contain proper modulations or intermittence (continuous, interrupted) which has been reported to be important for non-thermal effects as shown in [5], [6] and [7]. The third method is the usage of exposure systems based on a test cell phone and a Transverse Electromagnetic cell (TEM-cell), which allow exposing biological cells and animals to any pre-set signal of mobile communication, either from BTS or cell phones, containing proper modulations and time slots as e.g. in [8] and [9]. Whereas this approach is

feasible for many studies, it is limited by the pre-set functions of the test cell phone.

Most GSM/DCS/UMTS uplink signals has not been investigated so far in biological trials and nor studies were performed with the selected downlink signals. Recent meta-analysis of 17 studies showed negative health effects from BTS in so-called field studies, where the enrolled subjects were evaluated after RF exposure in the vicinity of BTS emitting multiple downlink signals simultaneously [10]. Though unblinded studies also showed effects, few double-blinded studies found no effects on human well-being. The comparison of these studies is limited due to a different and not always comprehensively described exposure conditions. Thus, laboratory studies with well-defined real BTS downlink signals would be needed to evaluate biological efficiency of exposure to RF from BTS. Our aim was to design a simple and cost-effective exposure unit providing a possibility for in vivo and in vitro trials which span a wide range of biological experiments with real GSM/UMTS signals from BTS [11].

## 2. Technical Details

We developed a RF exposure system that consists of three main parts: receiving unit, signal processing and conditioning unit and exposure unit (Fig. 1).



**Fig. 1:** BTS RF exposure system design. Tx represents transmitting antenna, Rx is receiving antenna. See text for further details.

The receiving unit (the donor antenna) is situated on the mast, which is placed on the top of a building. It receives the downlink signals from surrounding environment, i.e. it receives RF mobile communication signals from all mobile provider's BTSs in the vicinity of the building. This ensures that the signal fur-

ther used for both in vivo and in vitro studies is a real RF downlink signal. Donor antenna is the Yagi model SA1890.15 (ATT Plus, Holice, Czech Republic). The 15.875 mm Andrew Helix LDF4 - 50A coaxial cable suitable for 1–8800 MHz frequency band was used for connection. Subsequently, a received BTSs signal enters the signal processing and conditioning unit (AnyTone AT-6200, Qixiang electron science and technology, Quanzhou, China). This hardware was modified to disconnect an uplink signal, to prevent signal distribution and BTS site disturbing, and to split downlink into separate frequency bands. The downlink signal is filtered by AnyTone's integrated high selectivity pass-band filters, amplified to a required level, fed to the isolated output and to the transmitting (Tx) directional antenna with 50  $\Omega$  impedance mounted inside the exposure unit. The Tx antenna comprises of the one  $\lambda$  (where  $\lambda$  refers to a wavelength) loop dipole in dependence on signal (GSM900, DCS1800, or UMTS2100) and has aluminium alloy rugged cup-shaped reflector [12]. A laboratory holder allows changing distance between Tx antenna and exposed sample within the range 100–600 mm.

One-way amplifier of the signal processing and conditioning unit allows either selecting downlink frequency bands or coupling them together. Under our specific conditions, the downlink frequency bands were presented by GSM900 (935–960 MHz), DCS1800 (1805–1880 MHz), and UMTS2100 (2110–2170 MHz) signals. Our concept with external power amplifier, which is based on the Nokia DE34/DF34/DG35 (Nokia, Espoo, Finland) components, and allows increasing gain at the Tx antenna if the built-in one-way amplifier is not sufficient. Additional output from the power amplifier is plugged into a selective radiation meter Narda SRM3006 (Narda STS, Pfullingen, Germany) to calibrate the signal intensity and verify the selected frequency band.

All the terminal equipment has to follow the safety guidelines, as well as radio and EM compatibility compliances. Therefore, AnyTone AT-6200GD was issued by a certificate of compliance CE0678, assessed according to the European directive 1999/5/EC and also by the CSN ETSI EN 301 502, CSN 301 EN 489-1/-8, CSN EN 60950-1 as RF equipment covering EM compatibility, essential requirements for avoiding interference and safety requirements. Operation of the exposure unit is covered by the individual permission issued by the Regulatory authority for Electronic Communications and Postal Services SR.

A Faraday cage (ELPRA-Technik, Martin, Slovakia) is the main part of the exposure unit. It has dimensions of 1120  $\times$  450  $\times$  650 mm (L  $\times$  W  $\times$  H). The panning of the cage is composed of copper sheets with galvanized supporting frame that are well grounded to increase signal-to-noise ratio. The cage door, with di-

mensions of 300  $\times$  300 mm, is implemented on the front panel to make the interior of the Faraday cage accessible. The minimum shielding of 50 dB was achieved within 0.9–2.1 GHz frequency range. The right panel is made by a perforated sheet with the 5 mm circular openings. This sheet is overlapped by a 2  $\times$  2 mm aperture zinc plated mesh. This panel is suitable for the inner area illumination and also allows safe air circulation. The air in the laboratory room is conditioned by the mobile air conditioner ECG MK092 (Prague, Czech Republic) whereon the temperature can be set within the range of 17–30  $^{\circ}$ C. Humidity is regulated according to the hygienic standards for in vivo or in vitro experiments by the ultrasonic humidifier Boneco 7135 (Widnau, Switzerland). Disinfection of the air and surfaces is ensured by a germicidal ultraviolet lamp Prolux G M30W (Nexa, Piestany, Slovakia) with a programmable time switch.

The circular openings in the perforated panel are also convenient for the installation of communication links such as a thermal probe for temperature control, and a variety of sensors for monitoring the vital functions of an animal e.g. cardiovascular, brain activity, respiration, and ETCO<sub>2</sub> (end-tidal capnography). In particular, the system allows connecting a tracheal tube for the control of breathing in anaesthetized animals. Other diagnostic equipment (e.g. for electrocardiography or ultrasound) can be mounted through. If additional illumination is necessary, the battery powered LED lights are placed inside the cage to avoid any undesirable background noise and stray fields from AC supplied lights. A background magnetic flux density did not exceed 80 nT for the frequency band of 5–100 Hz, 60 nT for 100 Hz–10 kHz, and 40 nT for 10–100 kHz as measured with Narda EHP50-D (Narda Safety Test Solution, Pfullingen, Germany) at the location of exposure. The horizontal and vertical components of static magnetic field varied within  $20 \pm 6$  and  $39 \pm 4$   $\mu$ T, respectively as measured using a TM 75041 magnetometer (Izmiran, Troitsk, Russia).

There are two N-type connectors mounted on the cage's back panel. The input connector acts as a source feed for Tx antenna. Second connector serves as an output for additional information from receiving antenna (Rx) placed inside. Rx antenna is plugged to the selective radiation meter Narda SRM3006 that allows the measurement and analysis of signal dependent on a specific frequency range. While the measuring probes may have relatively large dimensions, we used the small sized 0.9/1.8/1.9 GHz triple band 1 W antenna for a mobile application having dimensions of 35  $\times$  6  $\times$  0.4 mm (YAGEO CAN 4313330109191B, New Taipei City, Taiwan). It provides the connection to the Narda SRM3006 with a possibility to use tripartite antennas in the near field measurements. However, one

axis antenna requires averaging of all three axes (X, Y and Z) to obtain an accurate result.

The inner sides of Faraday cage panels are upholstered by thick carbon foam. This precaution reduces uncontrolled reflections, which can produce standing waves in the exposure unit what could lead in a frequency dependent resonance maxima and non-uniform EM field intensity distribution [13].

### 3. Verification of Exposure System

The field distribution was experimentally checked in the exposure unit, which was either empty or "loaded" with a phantom. A lab glass with 250 ml physiological solution (0.9 % NaCl in distilled water) was placed in the middle of the cage bottom as a phantom substituting an exposed biological sample. The power at the Tx antenna was set to 20 dBm as verified by a directional coupler connected to the selective radiation meter Narda SRM3006. The broad band field meter is inserted inside the exposure unit to conduct measurements of the E-field within the exposure area. As a field meter served Narda NBM550 (Narda STS, Pfullingen, Germany) with the three axis E-probe within 100 kHz–3 GHz frequency range, which is designed for the E-field measurements in the near field. The International Commission for Non-Ionizing Radiation Protection (ICNIRP) specifies that RF EM measurements have to be averaged through 6 min intervals [14]. For the DCS1800 frequency band, we measured E-field during 6 min at 900 positions (450 empty and 450 loaded) situated 50 mm above the floor inside the cage. This distance was defined by the 50 mm thick styrodur foam imbedded at the bottom of the cage. The Tx antenna was gripped 250 mm above the measuring area in the centre of the exposure cage. The data obtained using DCS1800 frequency band (Fig. 2) led us to determine the "specimen area",  $150 \times 250$  mm, with E-field percent deviation (PD) less than 15 % for the in vivo or in vitro RF EM experiments (Tab. 1). PD measures the degree to which the values in the array (specimen area) differ from the mean:

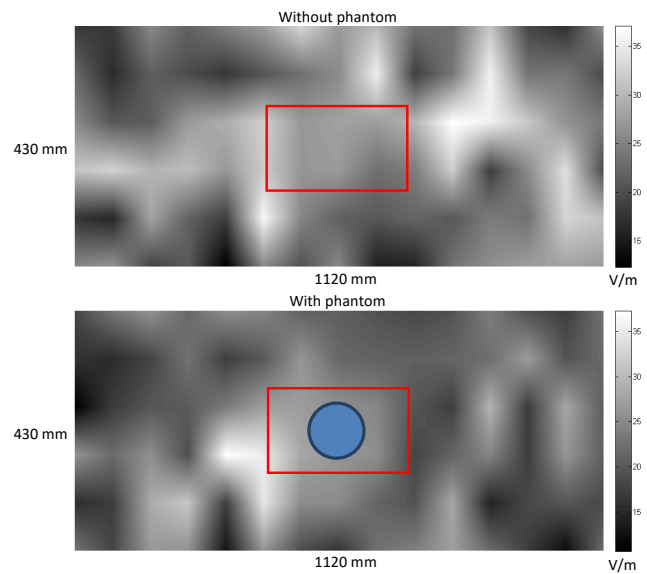
$$PD = \frac{\sum |\text{Experimental value} - \text{mean}|}{\text{no. of values} \cdot \text{mean}} \cdot 100. \quad (1)$$

Based on these findings the same specimen area was investigated also for GSM900 and UMTS2100 frequency bands. Thus, the 120 points (60 empty and 60 loaded) were recorded for both frequency bands to determine their E-field PD (Tab. 1). The E-field distribution for GSM900 (Fig. 3) yielded better deviation for the empty cage, but higher deviation for the loaded

**Tab. 1:** E-field distributions (average $\pm$ SD) within specimen area at 20 dBm exposure power for each frequency band for exposures without and with phantom.

Frequency band	Use of phantom	E-field distribution ( $\text{V}\cdot\text{m}^{-1}$ )	Percent deviation (%)
DCS1800	Empty	$26.68 \pm 4.69$	15
	Loaded	$24.58 \pm 3.58$	14
GSM900	Empty	$26.18 \pm 4.21$	13
	Loaded	$26.00 \pm 4.76$	17
UMTS2100	Empty	$28.79 \pm 5.44$	16
	Loaded	$25.10 \pm 4.87$	18

cage comparing to DCS1800. E-field distribution for UMTS2100 (Fig. 4) yielded the highest mean percent deviation comparing to the other frequency bands. The measurements also revealed the highest difference between an empty and a loaded state.



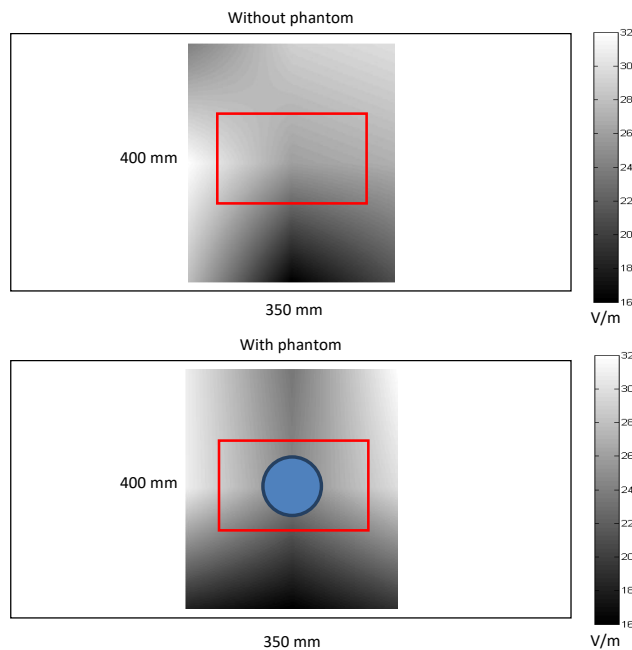
**Fig. 2:** E-field ( $\text{V}\cdot\text{m}^{-1}$ ) distribution measured in the DCS1800 frequency band 50 mm above bottom of exposure cage inside the exposure unit with and without the phantom, which represents an RF-exposed sample. The red square indicates the specimen area,  $150 \times 250$  mm, with minimum with E-field deviation less than 15 %. Blue circle designates the phantom.

These measurements confirmed that  $150 \times 250$  mm specimen area has PD less than 18 % for each of three studied frequency bands. Only a slight decrease (1–12 %) in E-field was revealed when the phantom was placed at the place of exposure (the specimen area). This impact of the phantom on E-field has to be taken into consideration before each experiment.

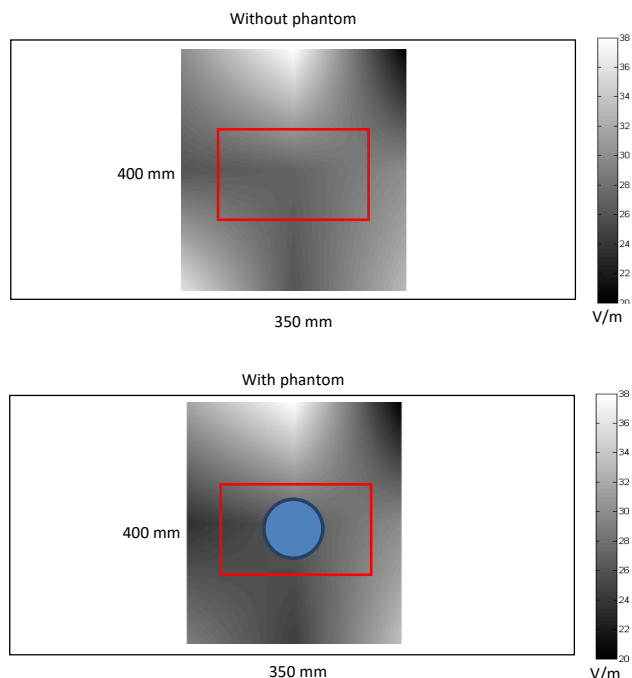
### 4. Discussion and Conclusion

We have successfully developed a simple and cost-effective exposure unit for exposure of biological ob-





**Fig. 3:** E-field ( $\text{V}\cdot\text{m}^{-1}$ ) distribution inside the exposure unit without and with the phantom. Square represents sample area for GSM900 frequency band measured 50 mm above bottom of exposure cage. The red square indicates the specimen area,  $150 \times 250$  mm, with E-field deviation less than 17 % percent. Blue circle designates the phantom.



**Fig. 4:** E-field ( $\text{V}\cdot\text{m}^{-1}$ ) distribution inside of exposure unit without and with the phantom, representing exposing sample. Square represents sample area for UMTS2100 frequency band measured 50 mm above bottom of exposure cage. The red square indicates the specimen area,  $150 \times 250$  mm, with E-field deviation less than 18 % percent. Blue circle designates the phantom.

jects to the real GSM/DCS/UMTS signals from the BTSs under well controlled conditions and where the specimen area was designed to reduce biomedical errors. Our measurements have shown that the exposure of biological objects with dimensions up to  $150 \times 250$  mm to RF signals of BTS is possible with E-field deviation less than 18 %. This exposure system can be helpful in the experiments with living organisms in in vivo and in vitro studies with physiological or pathological cells and other micro scale structures being exposed to RF EM fields from the base stations.

The biological effect of EM fields produced by the exposure system presented in here was described in the previous study [7]. The results revealed dystrophic changes in Purkinje cells and formation of  $\text{Fe}^{2+}$  depositions in various parts of rabbit's cerebellum comparing to control group after exposure to DCS1800 with E-field  $300 \text{ V}\cdot\text{m}^{-1}$  during 150 min. This study provided suggestion for pulse EM fields' wide bioactivity.

The study group Panagopoulos et al. [15] conducted several studies of *Drosophila melanogaster* exposure by using a cell phone in a talk mode for several minutes a day for 2–5 days, depending on a particular study. They observed a high degree of DNA fragmentation in the nuclei of ovarian cells compared to the control group. The fragmentation was highly dependent on the intensity and distance of the mobile phone from the exposed sample, with maximal effects observed at  $2.5 \text{ W}\cdot\text{m}^{-2}$  in close proximity and  $0.1 \text{ W}\cdot\text{m}^{-2}$  from distance of 20–30 cm. Obtained data [16] suggested that unpredictable variability in mobile telecommunication signals in combination with the fact that they are polarized and contain extremely low frequencies constitute the main reason for their strong bioactivity. A significant discrepancy is found among the results of experimental studies using the real exposure signals of commercially available handsets and the results of studies using a simulated or a generated signals or service mobile phones as proposed by health authorities (e.g. IARC). While experimental studies using simulated EL MAG fields show inconsistency among the results of which nearly 50 % of them showed no effects, studies using real signals showed almost 100 % consistency in the demonstration of adverse effects.

Limitation could be small dimensions of the exposure cage and the specimen area for human studies or larger animals *in vivo* studies.

Non-thermal studies have shown that in most cases are pulse EM fields more biologically active within a certain range (window) than similar exposure conducted by a generated or simulated EM source. Thus, we designed the exposure system that meets the requirements of laboratory procedures maintaining real GSM/DCS/UMTS uplink signals.

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